20th INTERNATIONAL WINTERSCHOOL

20th
2018 2018
International Winterschool
on New Developments in Solid State Physics
Mauterndorf Castle

NEW DEVELOPMENTS IN SOLID STATE PHYSICS
MAUTERNDORF, 25 FEBRUARY - 2 MARCH 2018

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Accurate modeling of interband cascade lasers

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Interband cascade lasers (ICLs) are very attractive sources in mid-infrared, because of their low threshold current. To date, ICLs mainly address the wavelength range from 3-5µm, which is believed to be sweet spot of this technology. In comparison to their main competitor, the quantum cascade lasers, they have much smaller threshold currents and voltages, but also lower output power levels. Their low dissipation makes them particularly interesting for on-chip integration of mid-infrared photonic sensors. A strong effort is currently put on the ICL development for longer wavelength [1]. There, ICLs typical have much higher threshold currents comparable to quantum cascade lasers. The progress in ICL research was mainly driven by experimental approaches, such as testing different material systems and growth studies. A major step in high-temperature performance of ICLs in general was achieved by rebalancing the internally generated carriers [2].

The aim of this work is to revisit the design strategies of interband cascade lasers based on a rigorous description of the internal processes using accurate and efficient modeling tools. In comparison to QCLs, ICL modeling is much more complicated and much less studied by the scientific community. Very little work has been done beyond solving the bandstructure in a multi-band scheme. This is roughly the same state of QCL modeling 15 years ago.

The minimum required steps to obtain a reasonable model are the following. A k-space resolved multi-band kp model is required to accurately describe the non-parabolic in-plane dispersion of conduction, valence and mixed states. The carrier density can be obtained from a simplified thermal quasi equilibrium approximation for the design process and rigorously from a semi-classical transport model using a generalized model valid for mixed states. Carrier transport requires intersubband scattering models that are generalized to multi-band non-parabolic subbands. Computationally the most costly part is the rigorous calculation of the Auger process in quantum wells that includes roughness and non-parabolic dispersion. The lack of an accurate Auger scattering model might be one of the major reasons, why the internal mechanisms and limits of ICLs are not sufficiently understood.

An efficient implementation of these steps is required in order to obtain a simulation tool that can be used during the design process. The current implementation uses a number of numeric tricks to speed-up the calculation. To give some examples, an exact block-diagonalized Hamiltonian and a fast iterative Eigen-solver is used. Cubic spline fits and harmonic decompositions are utilized to approximate the in-plane 2d k-space. Finally, the bandstructure can be calculated within 20-40s for one bias point on a notebook. The transport model and a cavity model are currently under development.

[1] A. Schade, S. Höfling, in: Proc. SPIE 10403, Infrared Remote Sensing and Instrumentation XXV, 1040305 (2017).

[2] I. Vurgaftman 1 , W.W. Bewley 1 , C.L. Canedy 1 , C.S. Kim 1 , M. Kim 1 , C.D. Merritt 1 , J. Abell 1 , J.R. Lindle 1 & J.R. Meyer, in: Nat. Commun. 2, 585 (2011).

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